Using Chaff with a Cloud Radar to Study Entrainment Processes in Small Cumulus

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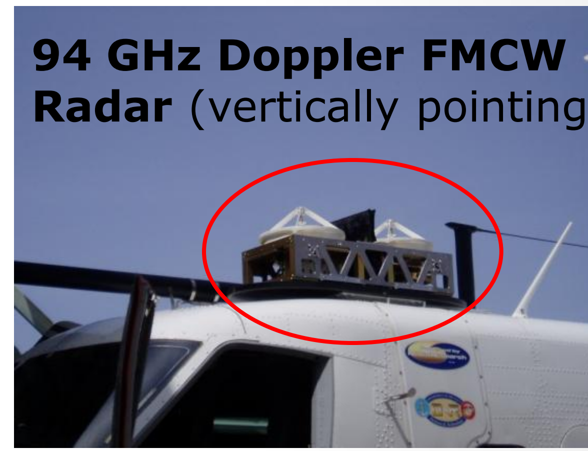
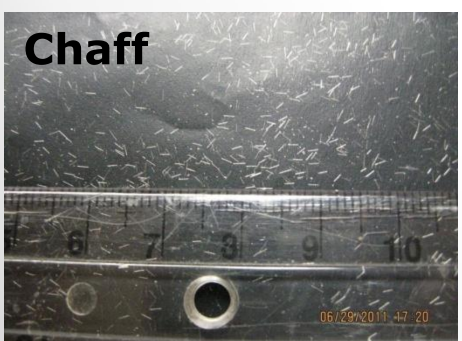


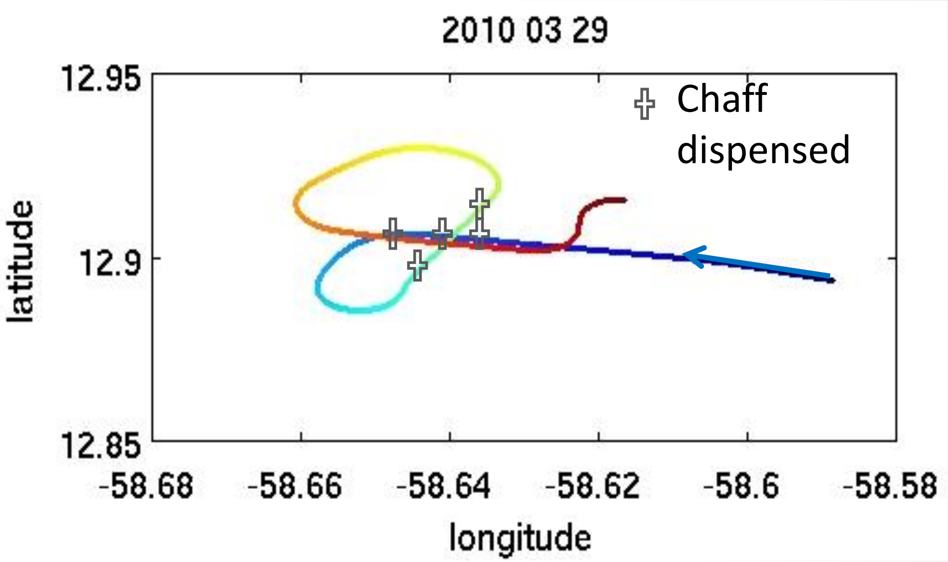


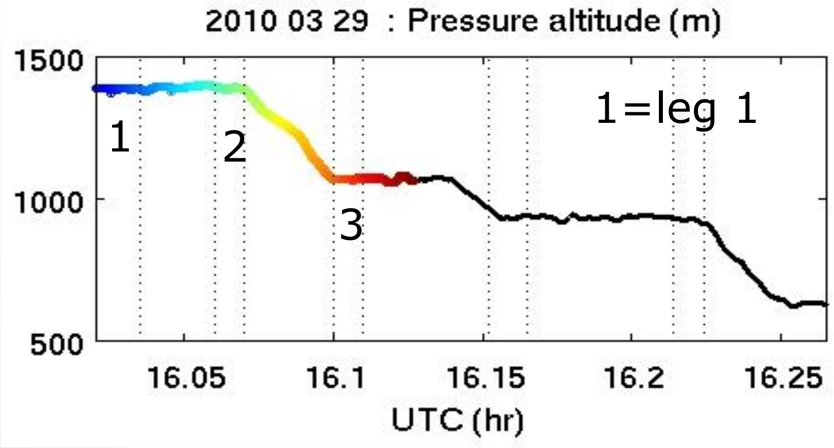
- pre-cut metallic coated fibers (cut to 3/4 mm-1/4 of the radar wavelength)

- the terminal velocity of the fibers is about 2 cm/s: they effectively track air motions

- dispersed near the cloud top and edge of small cumulus

Cloud studied: Taken 1 min prior to the leg 1





Method

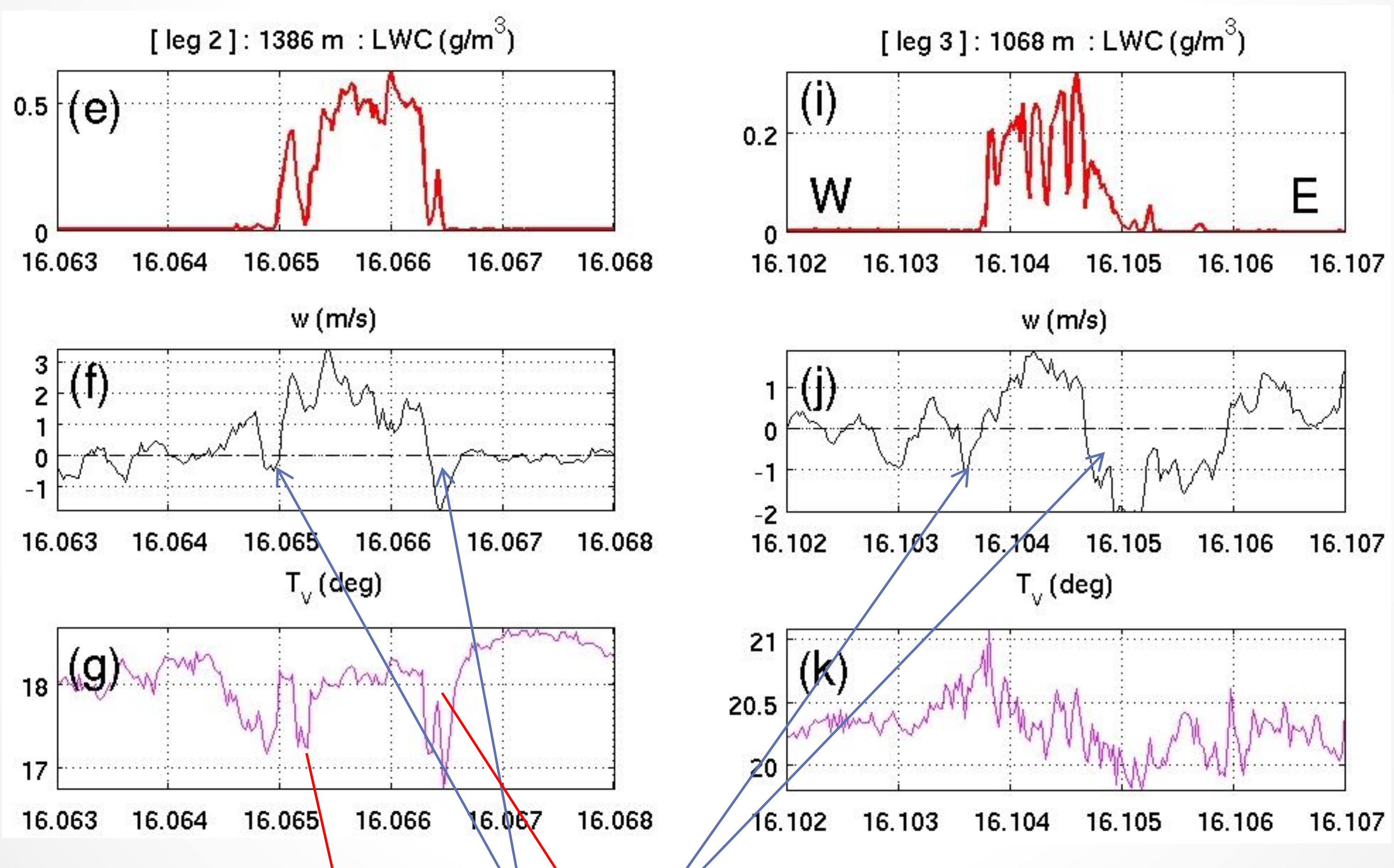
1. Chaff was dispensed (3-along and cross wind): time elapses from blue to red colors in above figure.

2. Aircraft made penetrations of the cloud of interest at lower levels to observe the chaff clouds above with the radar

Characteristics of the cloud (thermodynamic analyses)

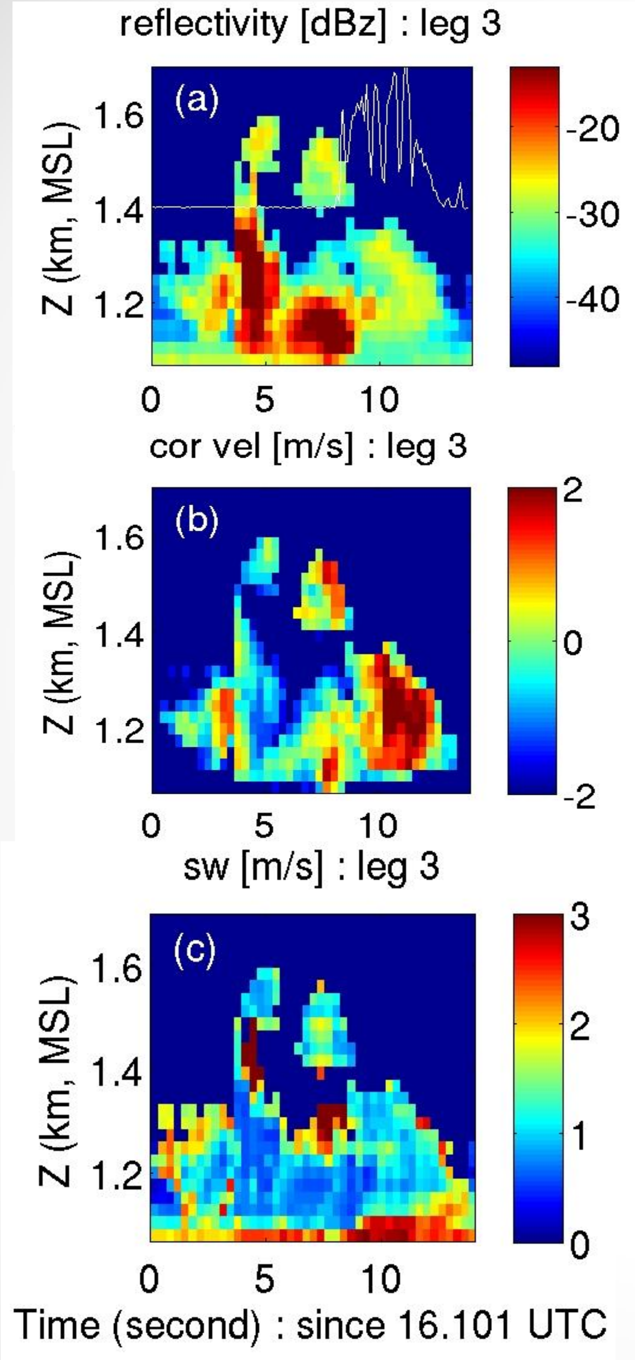
Leg 2 : working on chaff
(cross-wind direction)

Leg 3: after chaff dispensed
1000 feet lower than Leg2



Downdraft along the cloud,

lower temperature, negative buoyancy



Chaff detection from the radar : leg 3

(a) **Reflectivity**

Chaff descends along the cloud edge (outside) : refer to LWC+1.4 (white line)

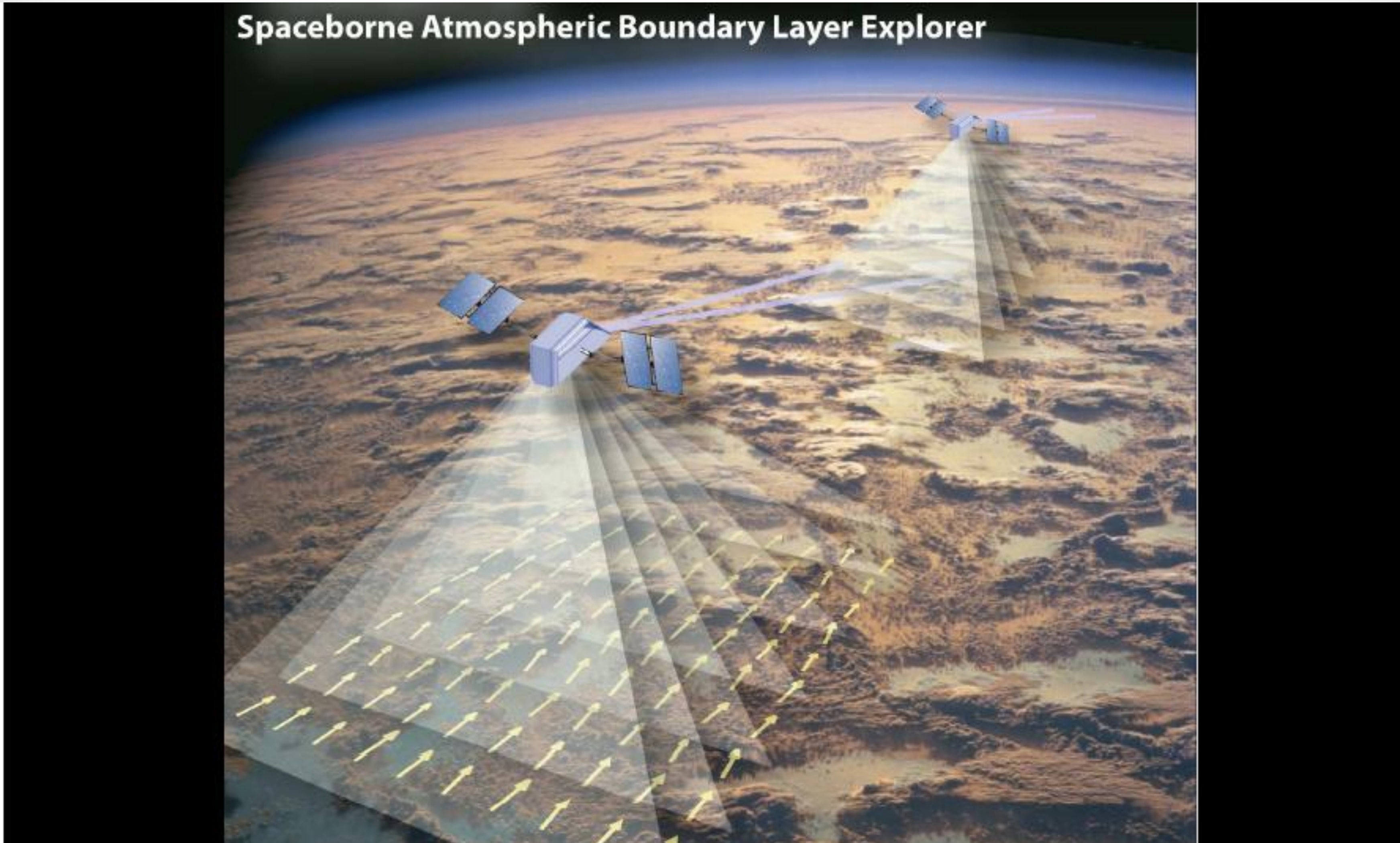
(b) **Doppler velocity**

- Downward motions where chaff descends
- Strong updraft along the upshear side of cloud (cloud droplets grow)

(c) **Spectrum width**

Narrow spectrum width where chaff observed

Mission will be proposed to the Earth System Science Pathfinder (ESSP) Program, Earth Venture (EV-2), Sept 2011



Overarching science goal: To reduce the largest source of uncertainty in predicting the magnitude of future greenhouse warming: the response of boundary layer clouds to climate change

Objective 1. Quantify, through observation, global cloud top entrainment rate (ER) —the key parameter that governs cloud lifecycle, structure, and variability in the marine ABL

Objective 2. Explore and quantify relationships between cloud thickness, cover, and ER to understand turbulence processes inside the cloudy boundary layer

Objective 3. Understand ABL cloud transitions by quantifying how ER affects cloud top height distribution and ABL vertical structure.

SABLE Goal: Quantify Entrainment Rates from Space

SABLE Measurements: Cloud top height and wind, ABL top and stratification

Entrainment rate

StereoCam cloud top winds

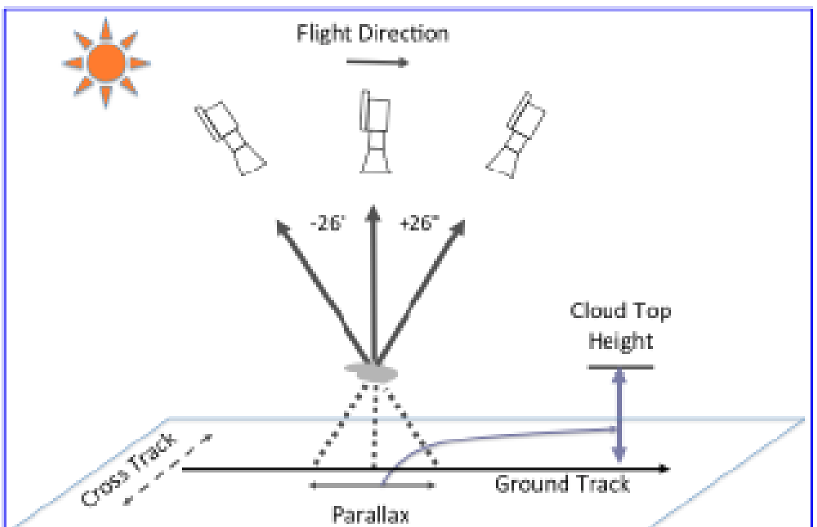
Subsidence rate from StereoCam divegergence and reanalysis

$$w_e = \mathbf{u} \cdot \nabla z_i + w_s$$

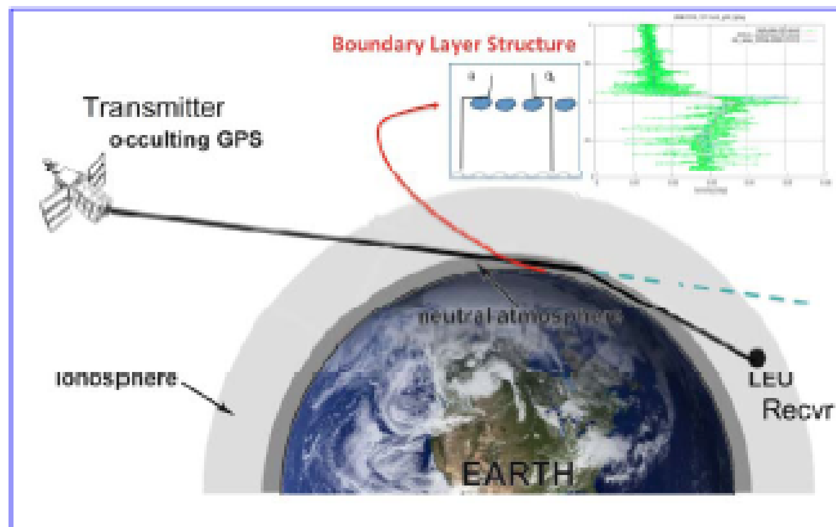
High-resolution (50 m) StereoCam/GPS RO cloud top height

SABLE Techniques: StereoCam + GPS/RO on Iridium-NEXT

Visible Stereoscopic Camera



GPS Radio Occultation



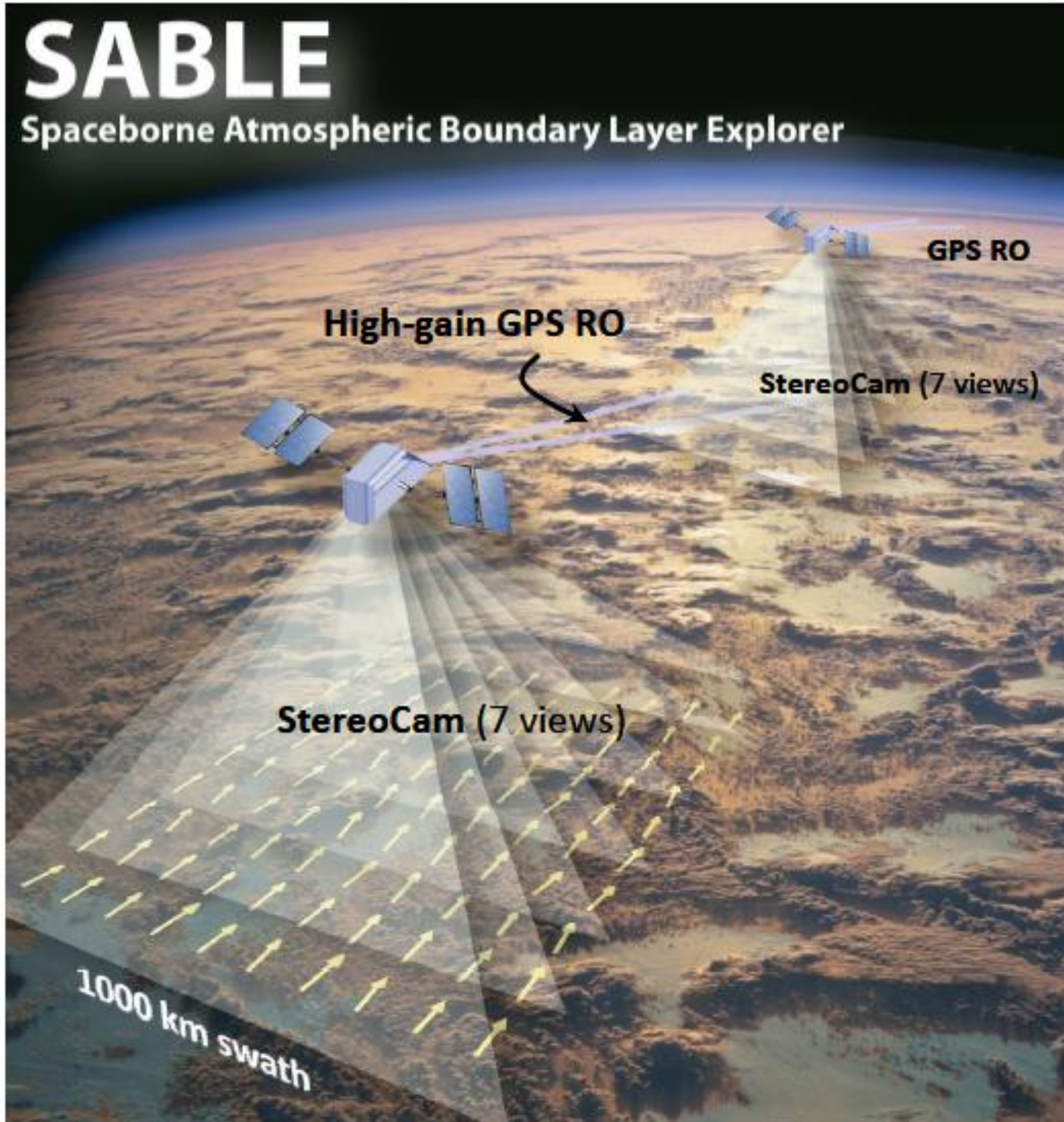
Observables:

StereoCam

- Cloud top height
(50 m absolute accuracy)
- Cloud top winds [u,v]
(0.3 m s^{-1} accuracy)
- Wind divergence
(3×10^{-7} s^{-1} accuracy)

GPS RO

- ABL top height
[hydrolapse]
(100 m accuracy)
- ABL humidity stratification
[q_v difference between lowest 500m and upper 500 m of ABL]
(0.5-1.0 g kg^{-1} accuracy)



Cloud-Environment Interface Studies

Pavlos Kollias
McGill University

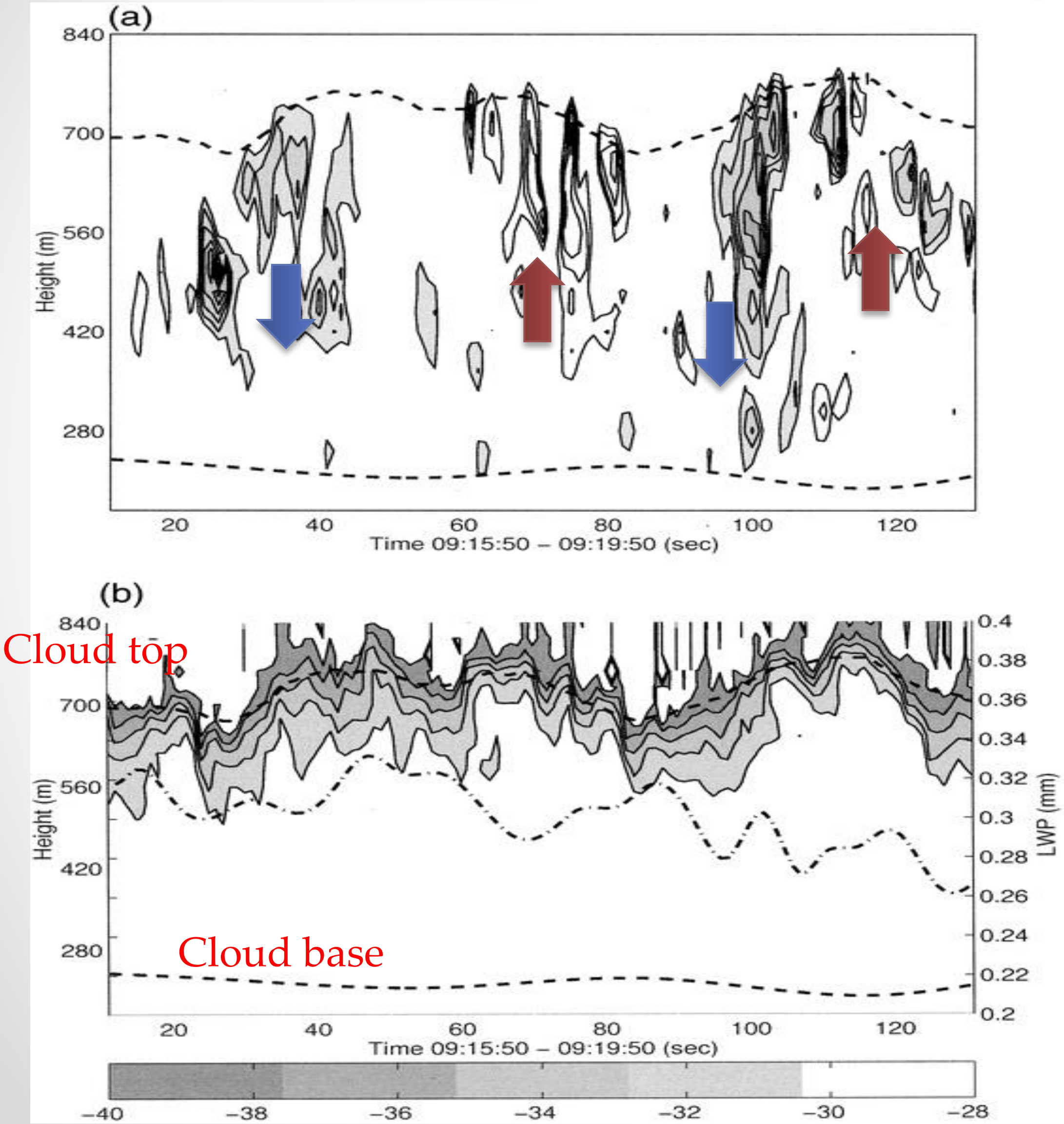
Where does entrainment occurs in the cloud?
Mechanism for air exchange at the interface?
(A. Blyth, NCAR)

The definition of entrainment depends on our ability to clearly define the boundary. This can be ambiguous in practice.
(C. Bretherton, UW)

Where entrainment occurs in clouds?

- There is a lack of consensus concerning the dominant location of the entrainment.
- Numerical studies of Heus et al. (2008) using LES and Lagrangian particle tracking indicate the lateral mixing as dominant with no evidence for significant cloud--top entrainment. These results are in agreement with the observational studies of Gerber et al. (2008) among others.
- However, in other studies the cloud top has been identified as a dominant region of the entrainment (e.g. Jensen et al. 1985, Lu et al. 2008). The observations of the generation of the larger drops predominately in cloud-top regions (e.g. Small and Chung 2008) suggest that the top entrainment may be important.
- According to Blyth (1988) the entrainment occurs near the ascending cloud top, followed by descent around the edges of the mixed parcels. The numerical simulations of Zhao and Austin (2005) support the shedding thermal model proposed by Blyth et al. (1988) and suggest that the vortical circulation is primary responsible for the large--scale entraining eddies. The importance of a recirculating vortex at the top of the ascending thermal for the entrainment has been discussed in Blyth (1993).

Radar reflectivity gradient near the cloud edge – Dry air intrusions are evident by inward (downdraft) velocities and reduced reflectivities near the cloud boundaries (top)



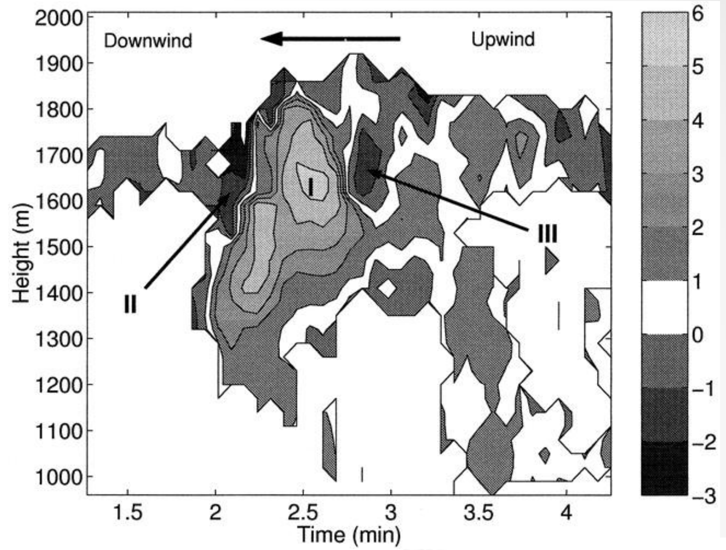
(a) Detailed view of the vertical velocity contour for a small segment of observations (0915:50–0919:50 UTC) where the downdraft structures are shaded. The updrafts and downdrafts with absolute velocities more than 1 m s^{-1} are shown and the contours are plotted with 0.5 m s^{-1} interval. The cloud boundaries are also shown.

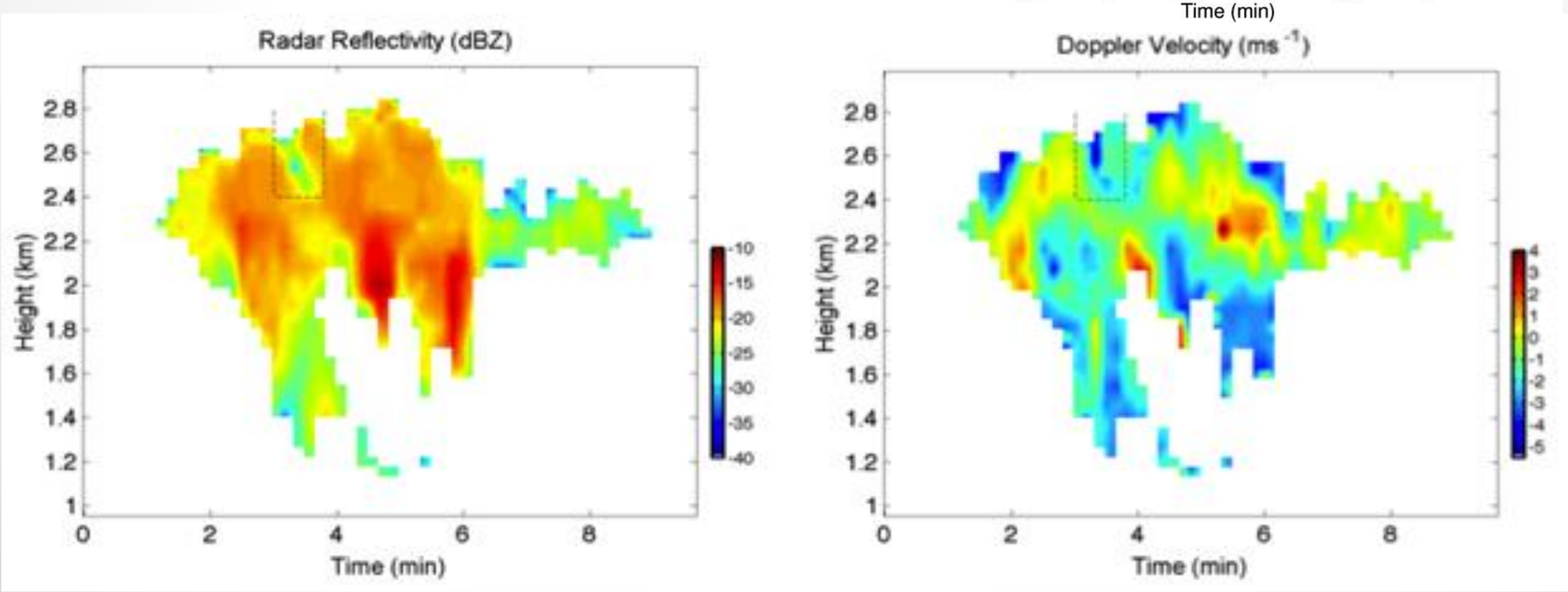
(b) Radar reflectivity contour from −31 to −40 dBZ near the cloud top, where the cloud boundaries are also shown. The dot–dashed line is the LWP for the same period

Kollias and Albrecht, 2000

Doppler Measurements

- Evidence of penetrating downdrafts and descending shell (Kollias et al., 2001)





Doppler Measurements

- In addition to the profiling radars Doppler measurements, for the first time we will have systematic observations of the horizontal wind component in clouds using the Doppler velocity field from the scanning cloud radars

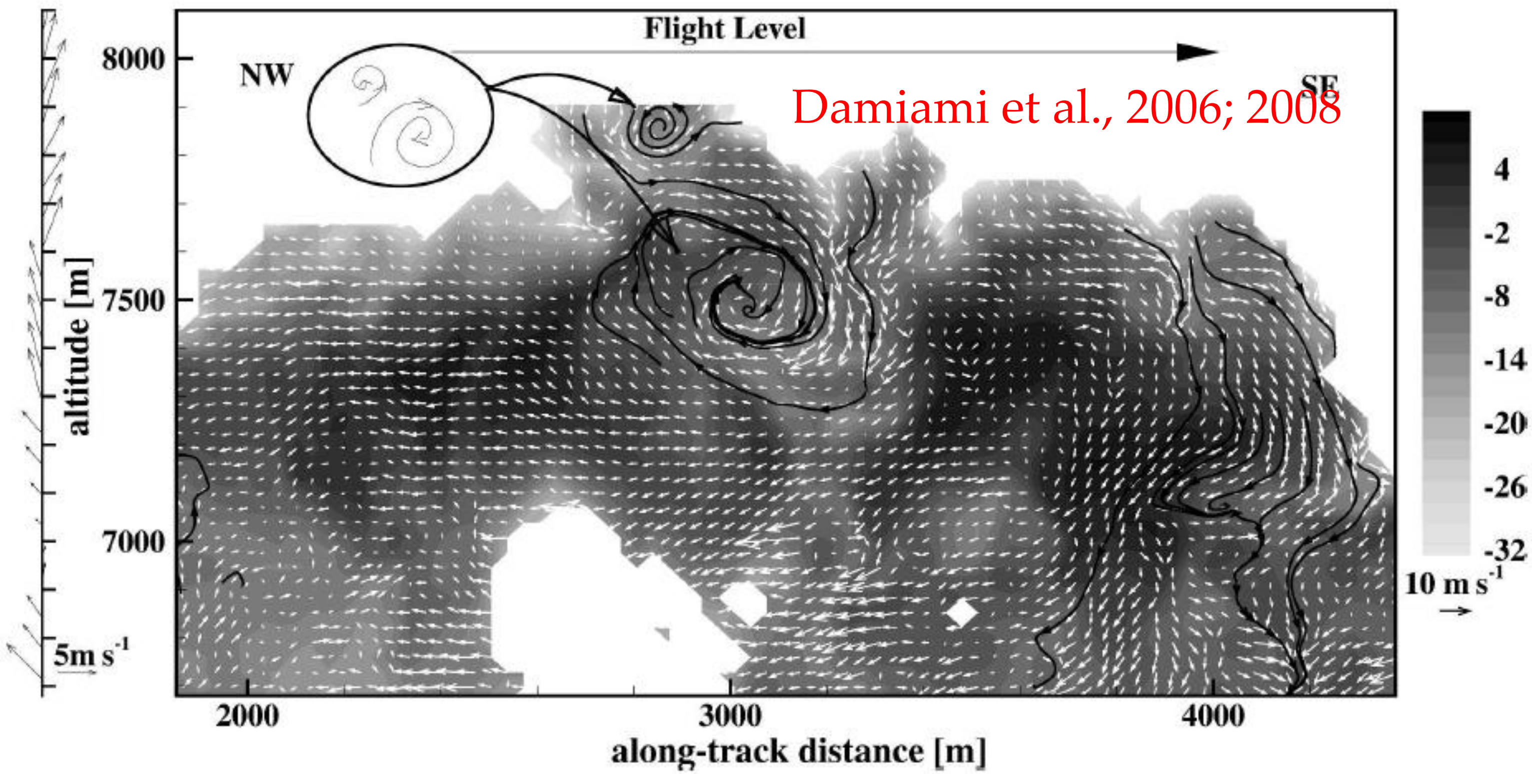


FIG. 11. As in Fig. 6 but for a VPDD analysis of a turret developing in a large congestus at 2142 UTC 17 Jul 2003. The vectors on the left are best estimates of the wind from sounding data: the vector horizontal and vertical components have to be read as along and normal to the grid plane (upward means into the grid plane). Grid orientation is 134°, resolution 34 × 31 m^2.

Doppler Measurements

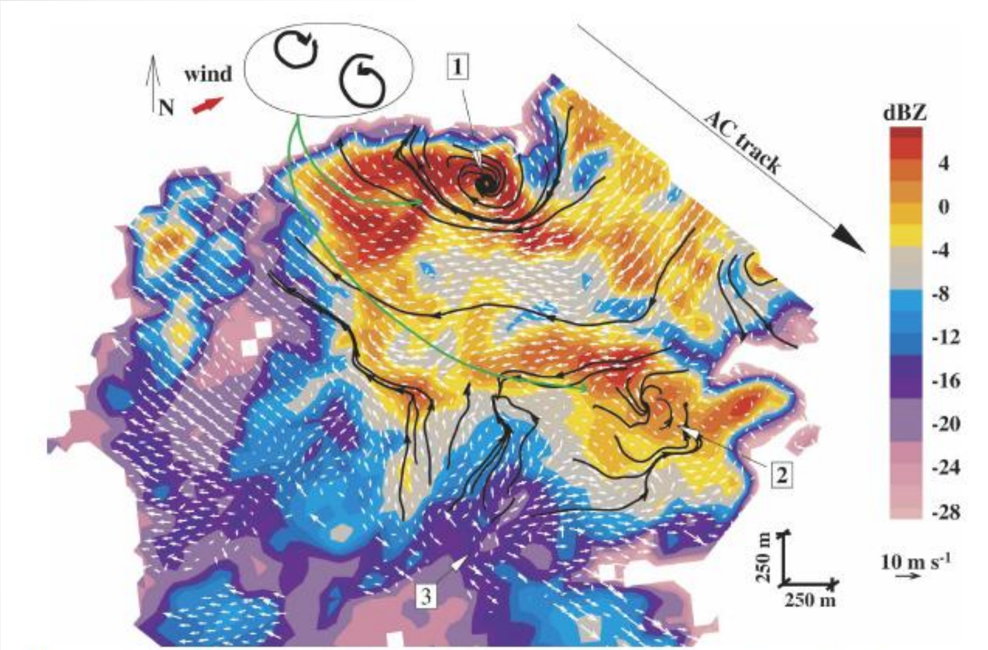


FIG. 4. Same as Fig. 3e but for a horizontal section showing a CVP from 2050 UTC 17 Jul 2003, at 7900 m MSL. Filled contours are reflectivity (dBZ). Labels 1 and 2 point to the centers of the CVP and label 3 to the region of horizontally diverging flow. Thick lines in the inset figure at top left are a conceptual interpretation of the CVP. Flight level ambient wind was 242° at ~7 m s^{-1} (arrow not to scale for better visualization).

Multiple thermals

Successive pulses

Active and decaying cloud parts

Existence of toroidal thermals (Scores and Ludlam, 1953

Large scale (100-500 m) intrusions of dry air

Small-scale turbulence at the cloud-top

Characterize the Sharpness of the cloud edge

- Gradient of Z (conditionally LWC) across the cloud edge
- Gradient of vertical air motion (Doppler) – divergence

Challenges:

- Our sensors can also “misrepresent” the sharpness of the interface
- Need a mechanism to detect “clear air motion”
- (Bragg scattering and/or use of chaff)

Radar-based capabilities

- Cloud top height and velocity
- Eddy dissipation rate measurements
- Detection of large droplets
- Temporal evolution of cloud elements